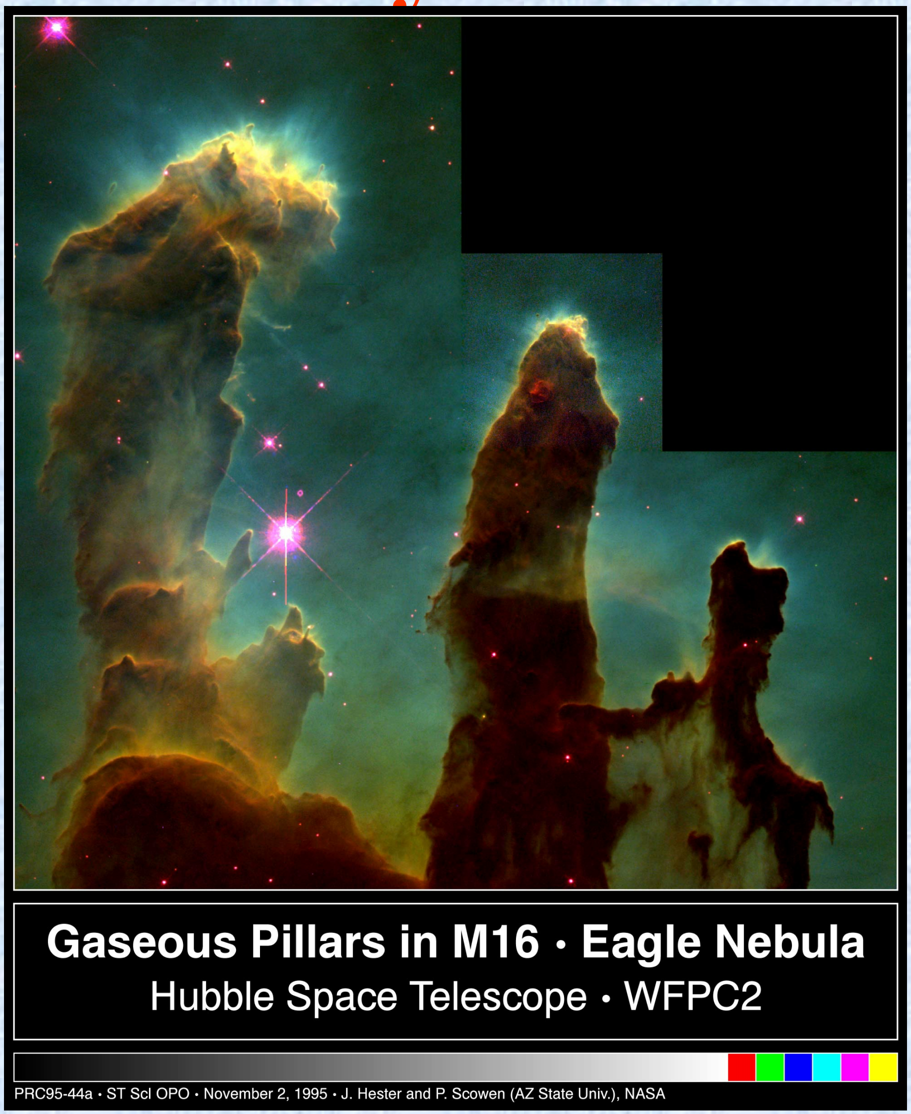
Astronomy 1 – Fall 2019

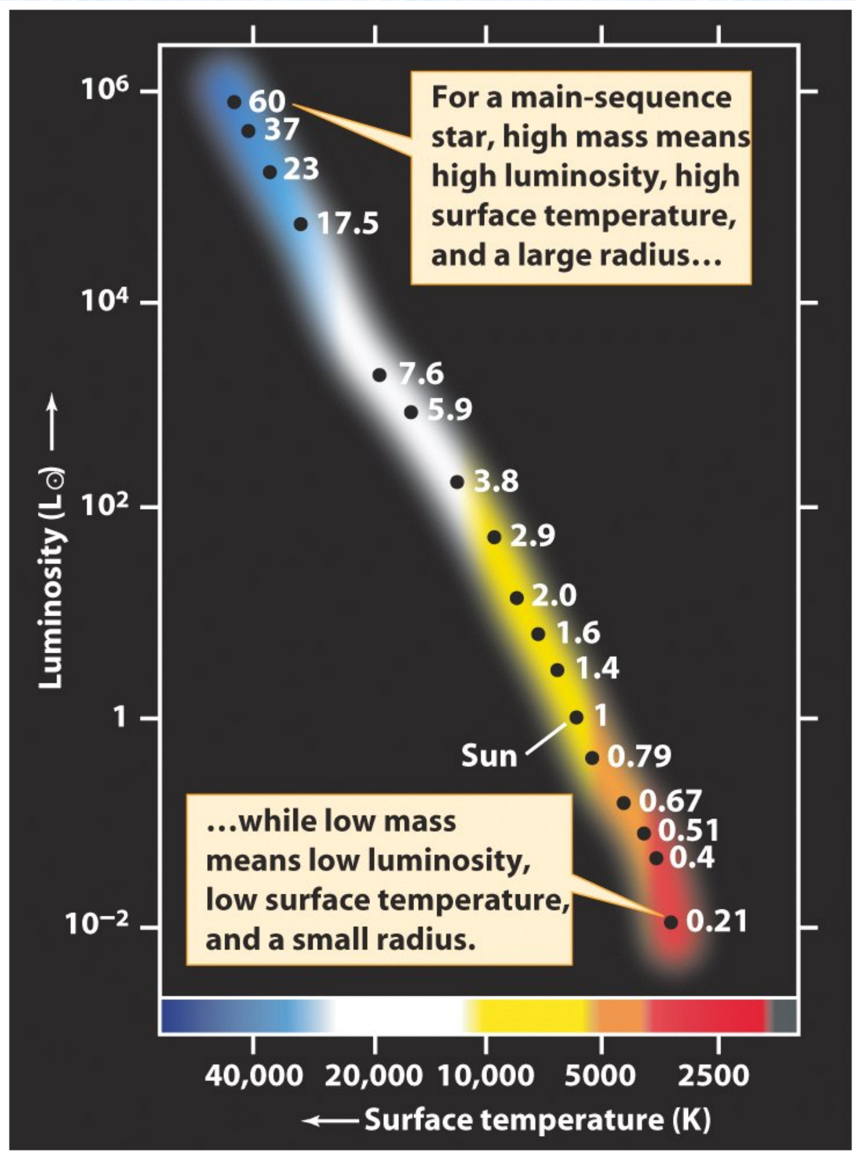


Lecture11; November 6, 2019

Previously on Astro-1

- Introduction to stars
- Measuring distances
- Inverse square law: luminosity vs brightness
- Colors and spectral types, the Hertzsprung-Russell diagram
- Masses of stars

- **The HR Diagram is a mass sequence for H burning stars.**



Today on Astro-1

- Massive stars are young stars
  - Mass determines lifetime of a star.
- Star formation
  - Where do stars form?
  - How do stars reach the Main Sequence?
  - How do protostars transition to the Main Sequence?
- Where do new stars form within galaxies?
- When did most of the stars in the Universe form?

The mass of stars determines their lifetimes.

All main-sequence stars are made of the same stuff, mainly H and He.

So why do massive stars have shorter lifetimes?

After all, they have more fuel to burn.

Massive Stars are More Luminous

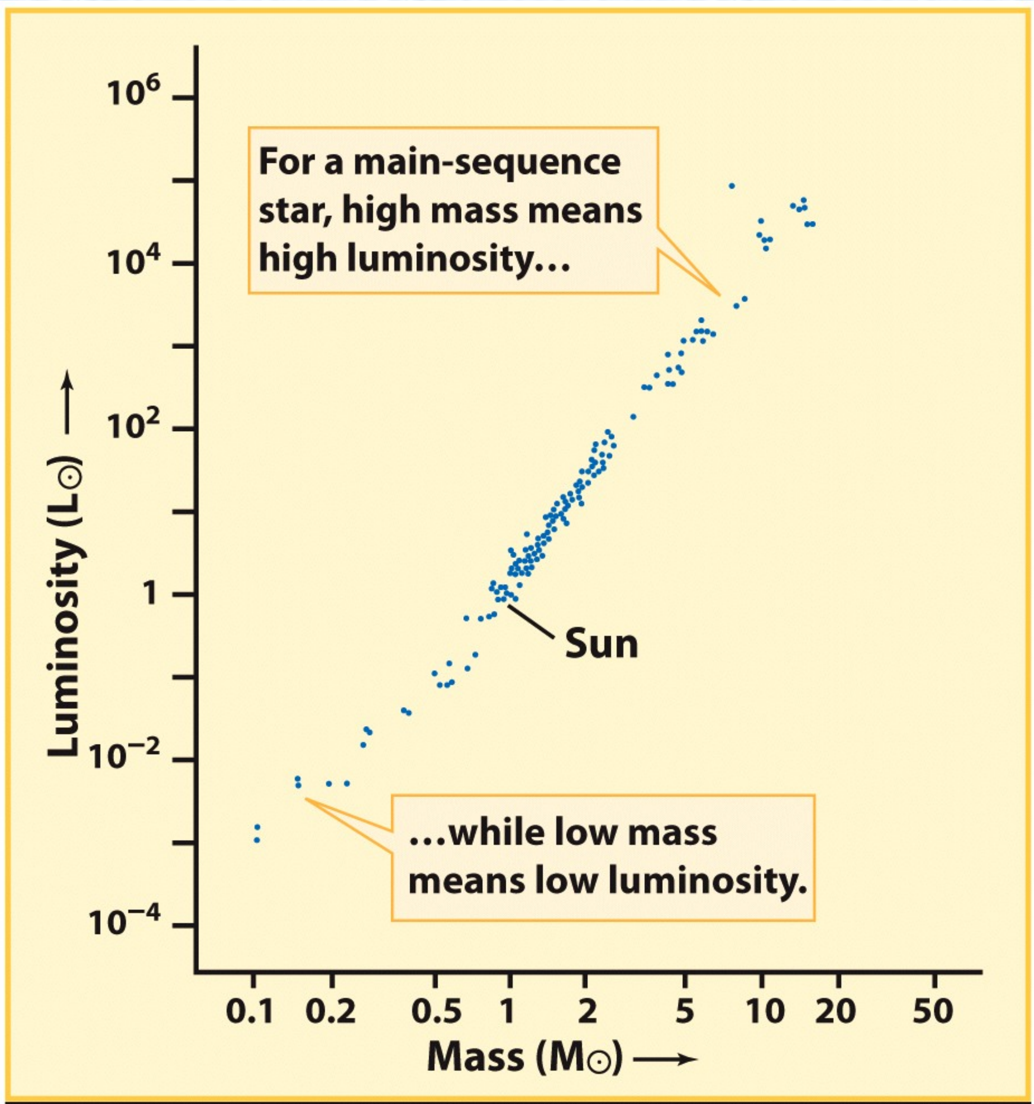


Figure 17-22
Universe, Tenth Edition

$L \approx L_0 \, (M/M_0)^{3.5}$

- A star with 60 times the mass of the Sun has 60 times as much nuclear fuel as the Sun, but burns it H more rapidly.
- $L/\ L_0 = (60)^{3.5,}$ or 1.67×10^6 times as rapidly!

Why Are Massive Stars More Luminous?

• Greater mass means greater central pressure & temperature.

Hydrostatic equilibrium requires more P to hold up the extra mass.

• So the nuclear reactions produce more power in the core.

A bit like a turbo-charged engine produces more power.

• And the surface luminosity balances the power production in the core, so a massive star is more luminous.

Massive Stars Lead Short Lives

Lifetime = Fusion Energy / (Luminosity), or

t_{MS} = ε M / L, where ε is $0.007c^2$ of the core mass.

- Let's scale from the main sequence lifetime of the Sun, which is 10^{10} yr.
- A massive star has a main sequence lifetime of

$$t_{MS} = t_0 (M/L) / (M_0/L_0) = t_0 (M/M_0) (L_0/L)$$
$$= t_0 (M/M_0)^{-2.5}$$

- Massive stars lead short lives.
  - A 60 M_0 spends 10^{10} yr $(1/60)^{2.5} = 4 \times 10^5$ yr on the main sequence.
  - A 25 M_0 star burns up its core H in 3×10^6 yr
  - *Shorter than the time it takes to orbit around the center of the Milky Way galaxy even once (200 Myr).*
  - Long enough for life to evolve? [See HW6 (U11.19.8)]

Approximately how long will a 3-solar-mass star spend on the main sequence?

A. 3 times the Sun's main-sequence lifetime

B. 0.33 times the Sun's main-sequence lifetime

C. 0.13 times the Sun's main-sequence lifetime

D. 0.11 times the Sun's main-sequence lifetime

E. 0.064 times the Sun's main-sequence lifetime

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Bonus Question:

How many times would a 3 solar mass star in the solar neighborhood orbit the center of the Milky Way before it used up its hydrogen fuel?

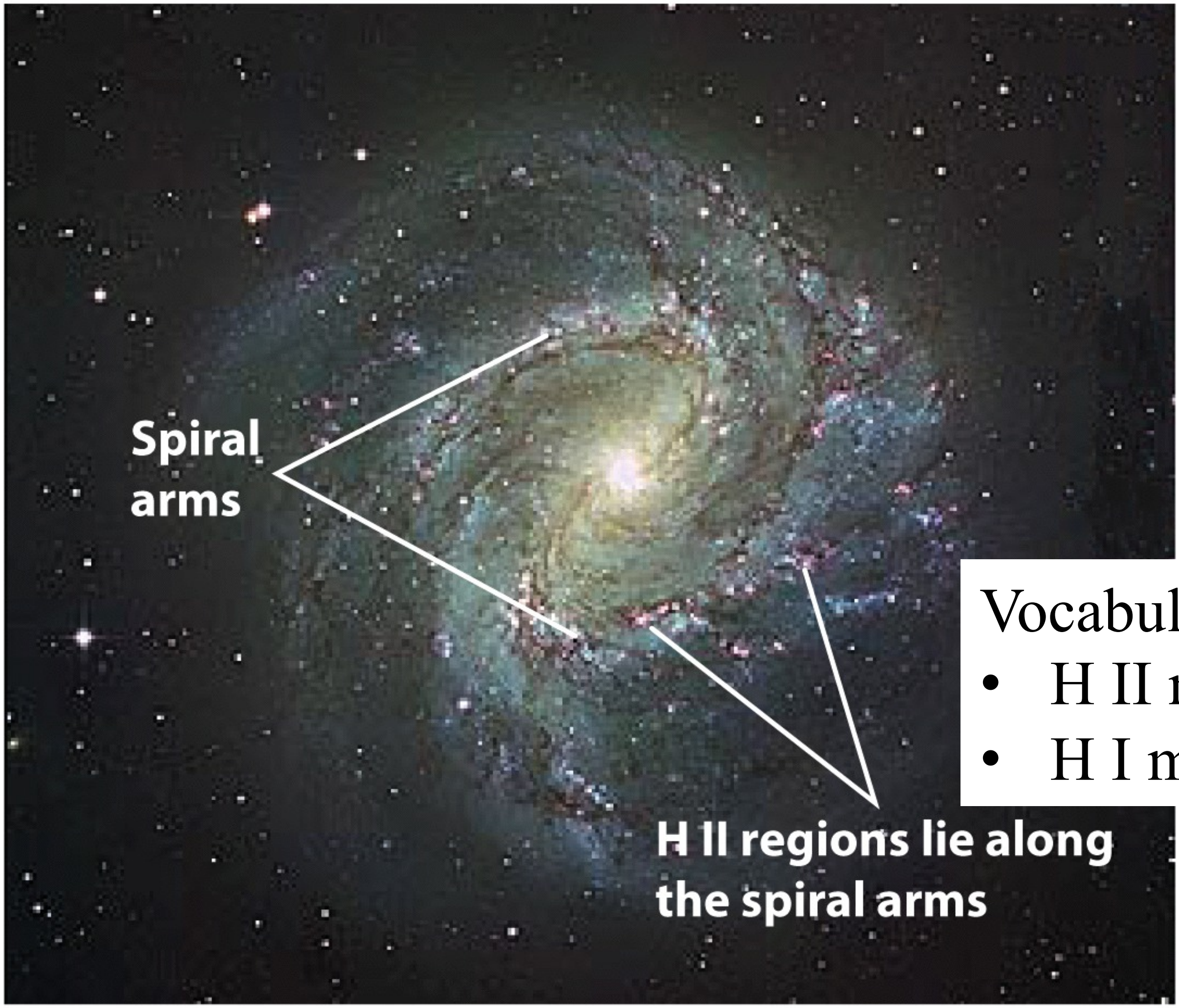
A19.2

Where do stars form?

Massive stars don't hang around for long, so they mark sites of recent star formation.

We can identify star-forming regions by locating massive stars in a galaxy.

Star-forming regions in another galaxy



We see spiral galaxy M83 nearly face-on

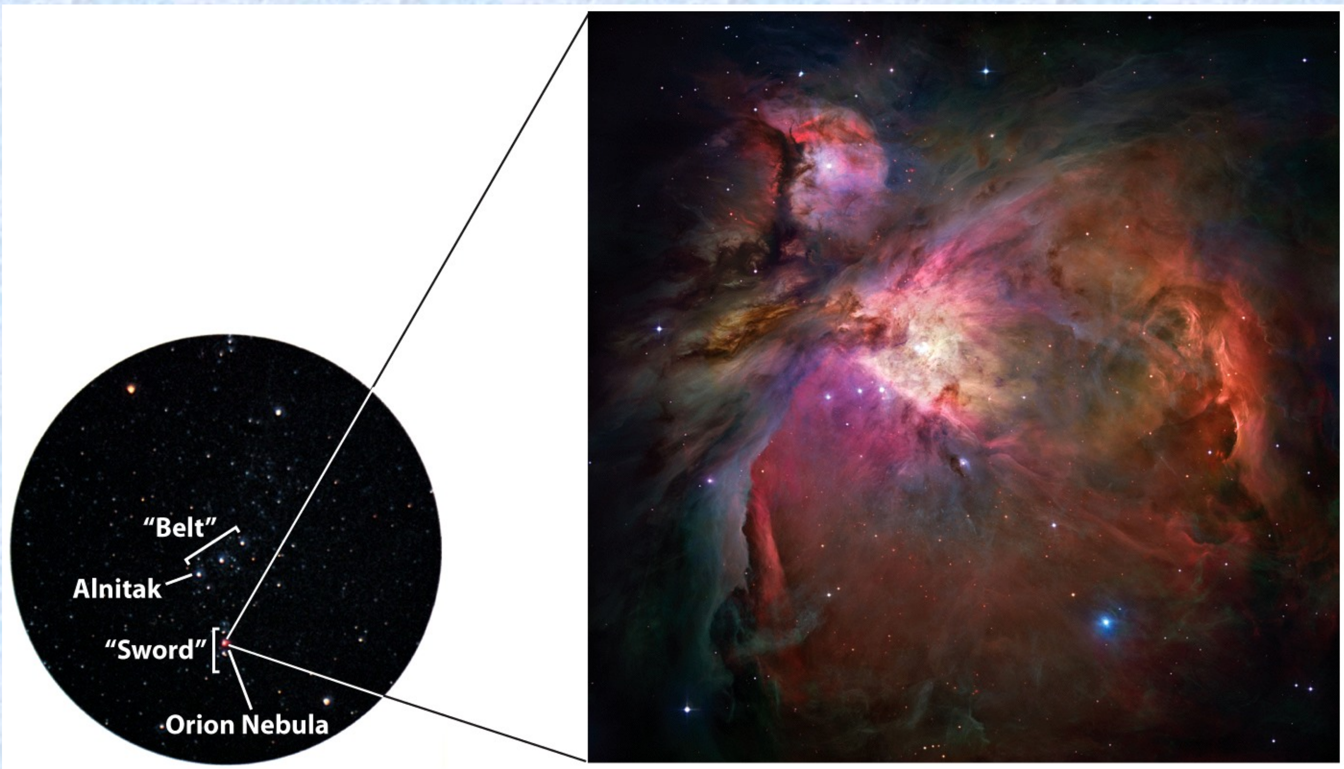
Figure 18-8a
Universe, Tenth Edition
Australian Astronomical Observatory/David Malin Images

Vocabulary:

- H II means ionized H, or H^+
- H I means neutral H, or H^0

Example of an H II Region (or Emission Nebula): The Orion Nebula

- Contains about 300 M_0 of gas and stars
- Illuminated by the five most massive stars
  - UV light excites the atoms, which fluoresce



(a) A wide-angle view of Orion **(b) A closeup of the Orion Nebula**

Figure 18-1
Universe, Tenth Edition
a: Australian Astronomical Observatory/David Malin Images; b: NASA,ESA, M. Robberto [Space Telescope Science Institute/ESA] and the Hubble Space Telescope Orion Treasury Project Team

Emission Nebulae: Ultraviolet light from massive stars is converted into lower energy photons

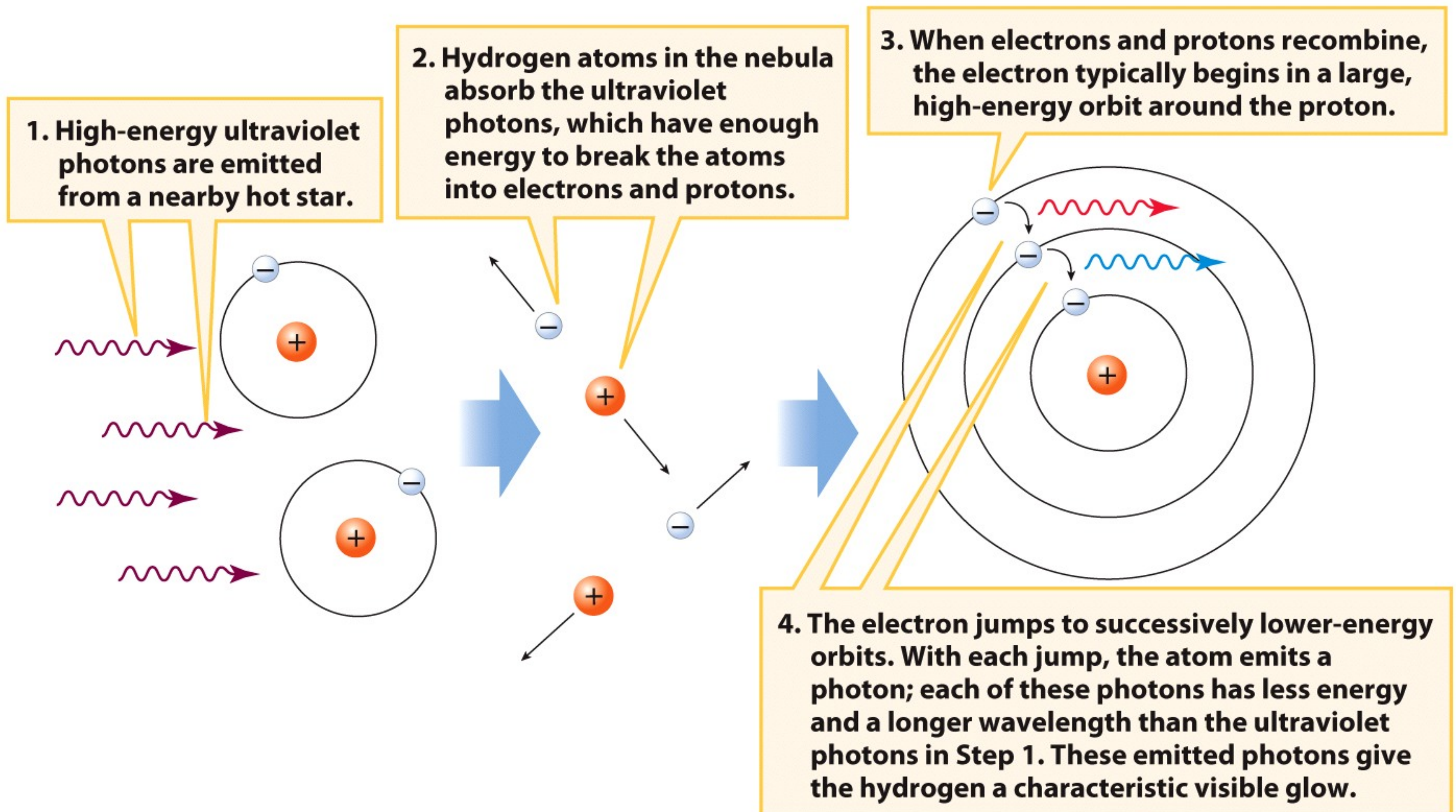


Figure 18-3
Universe, Tenth Edition

Emission, Reflection, and Dark Nebulae in Orion

A wide-angle view of Orion

Figure 18-1a
Universe, Tenth Edition
Australian Astronomical Observatory/David Malin Images

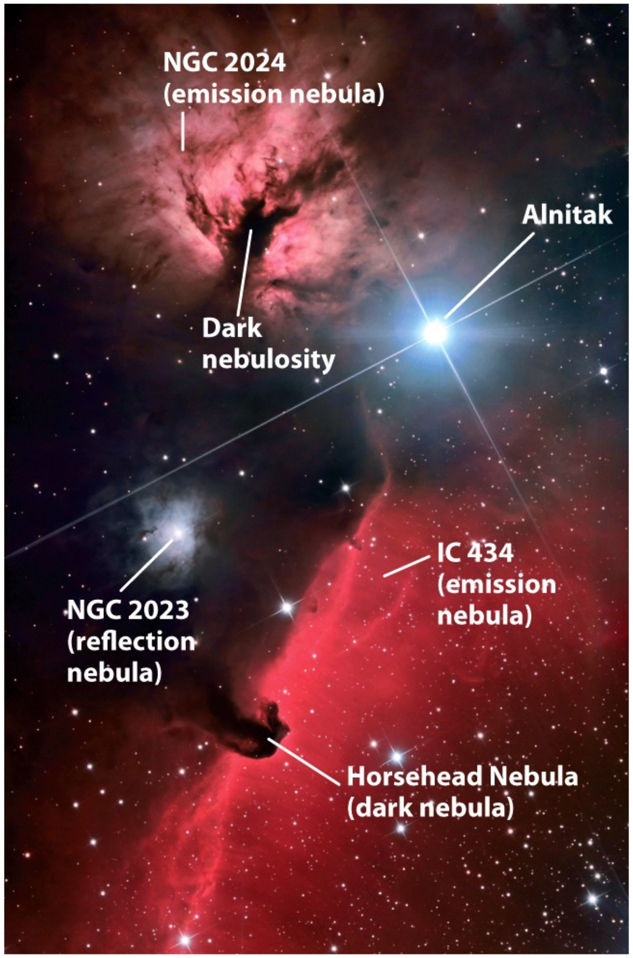


Figure 18-2
Universe, Tenth Edition
Stocktrek Images/Roth Ritter/Stocktrek Images/Corbis

Dark Nebulae are Opaque

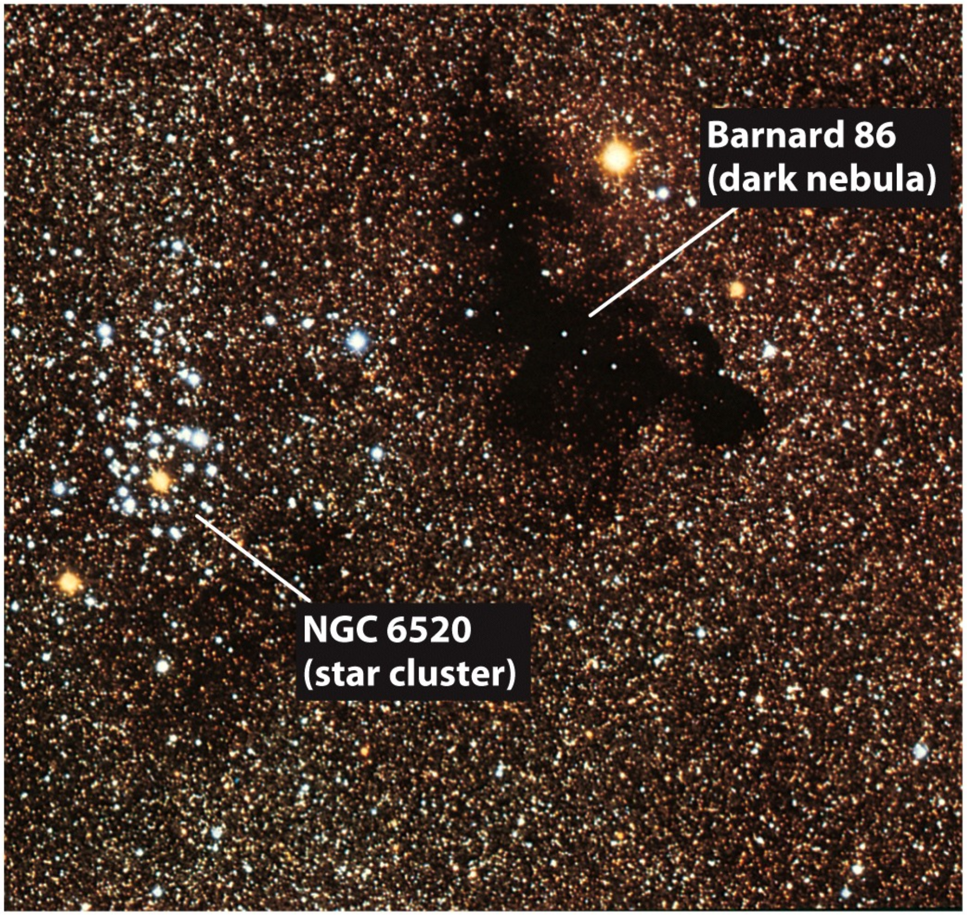


Figure 18-4
Universe, Tenth Edition
Australian Astronomical Observatory/David Malin Images

- Barnard 86 is about 1/7th the angular diameter of the full moon.
- Dust completely blocks optical starlight. Radio waves pass right through.
- Cold. T = 10 K.
- Do dark nebulae emit light?

Dust also reflects and scatters light

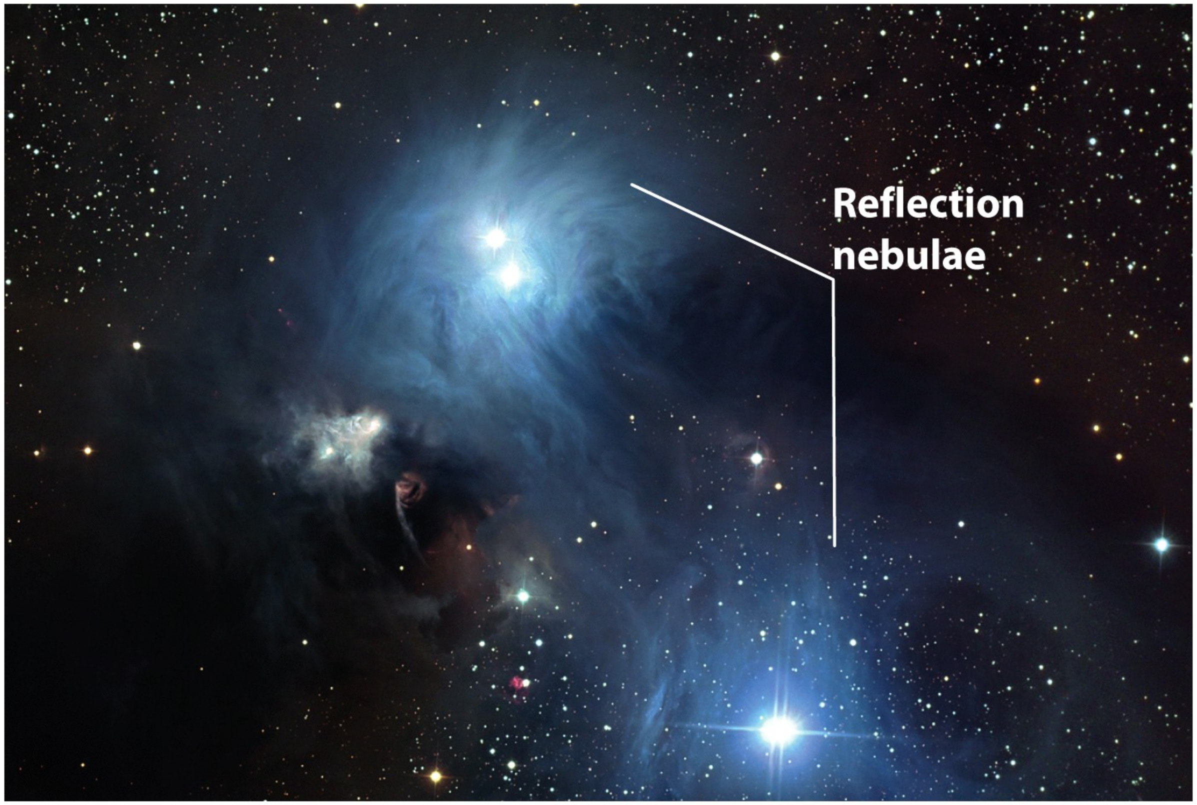
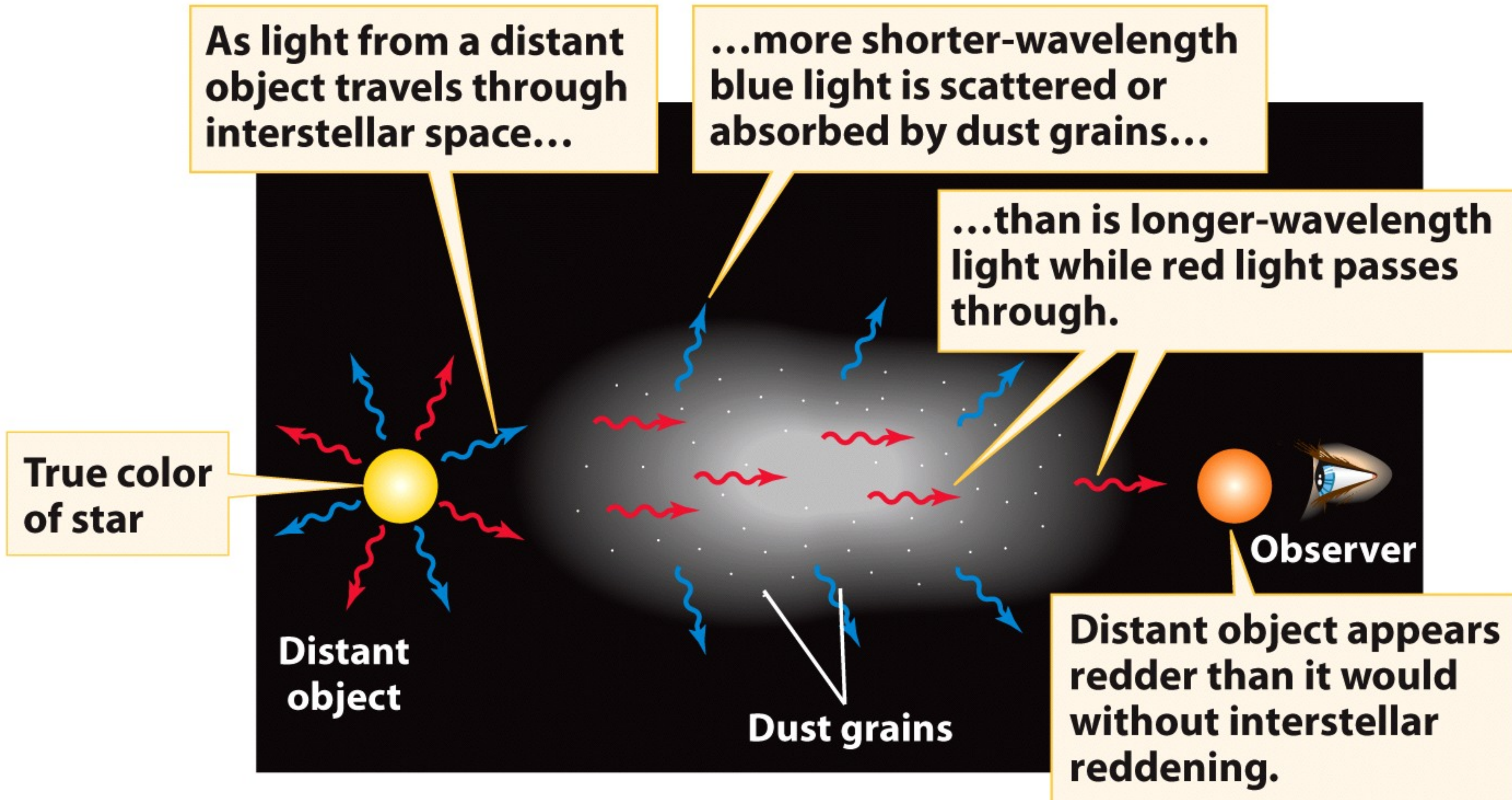


Figure 18-5
Universe, Tenth Edition
Dr. Stefan Binnewies and Josef Popsel/ww.capella-observatory.com

Reflection nebulae scatter and reflect light from the stars they surround

Interstellar Extinction & Reddening



How dust causes interstellar reddening

Figure 18-6a
Universe, Tenth Edition

We see spiral galaxy NGC 891 nearly edge-on

Figure 18-8b
Universe, Tenth Edition
Instituto de Astrofísica de Canarias/Royal Greenwich Observatory/David Malin

Midplane of the Milky Way Galaxy

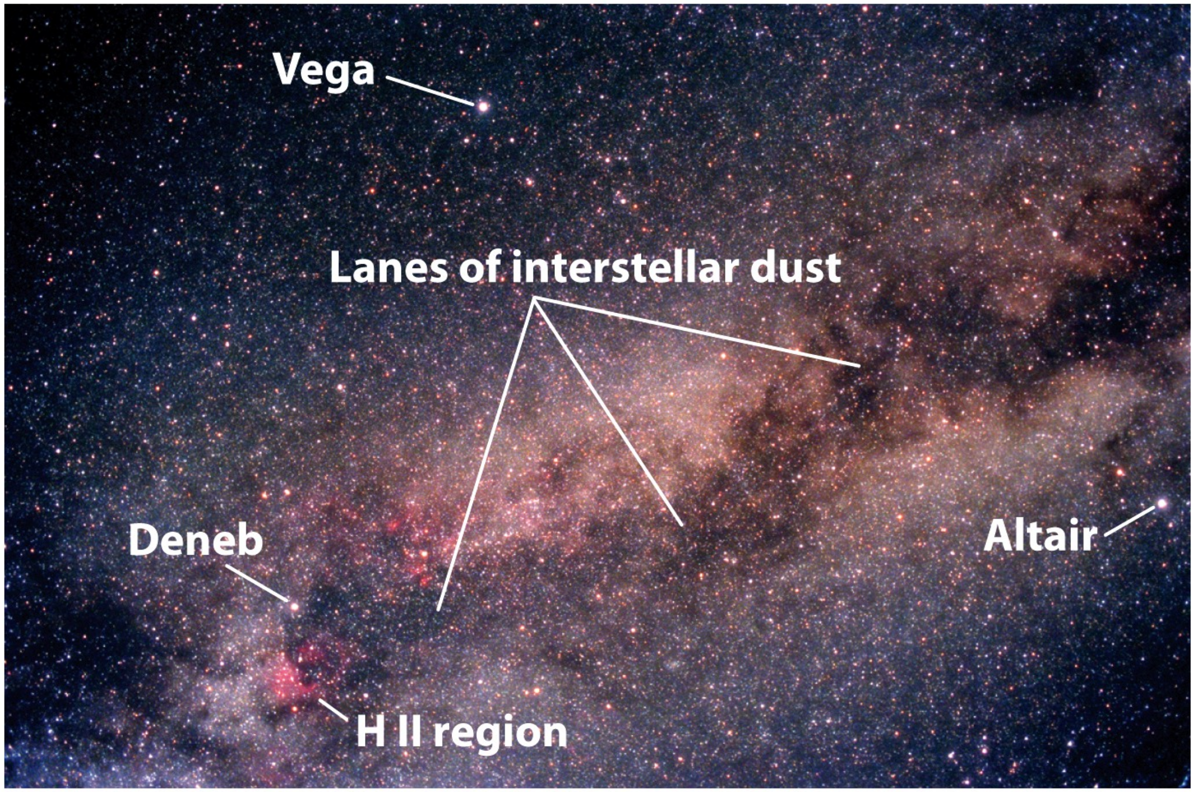


Figure 18-7
Universe, Tenth Edition
Jerry Lodriguss/Science Source

HW6: Extinction toward a star cluster 3 kpc away. Told that 15% of the light gets transmitted every kpc. How much of the light gets through?

How does interstellar dust affect measurements of stellar luminosity?

Mass Loss from a Supermassive Star

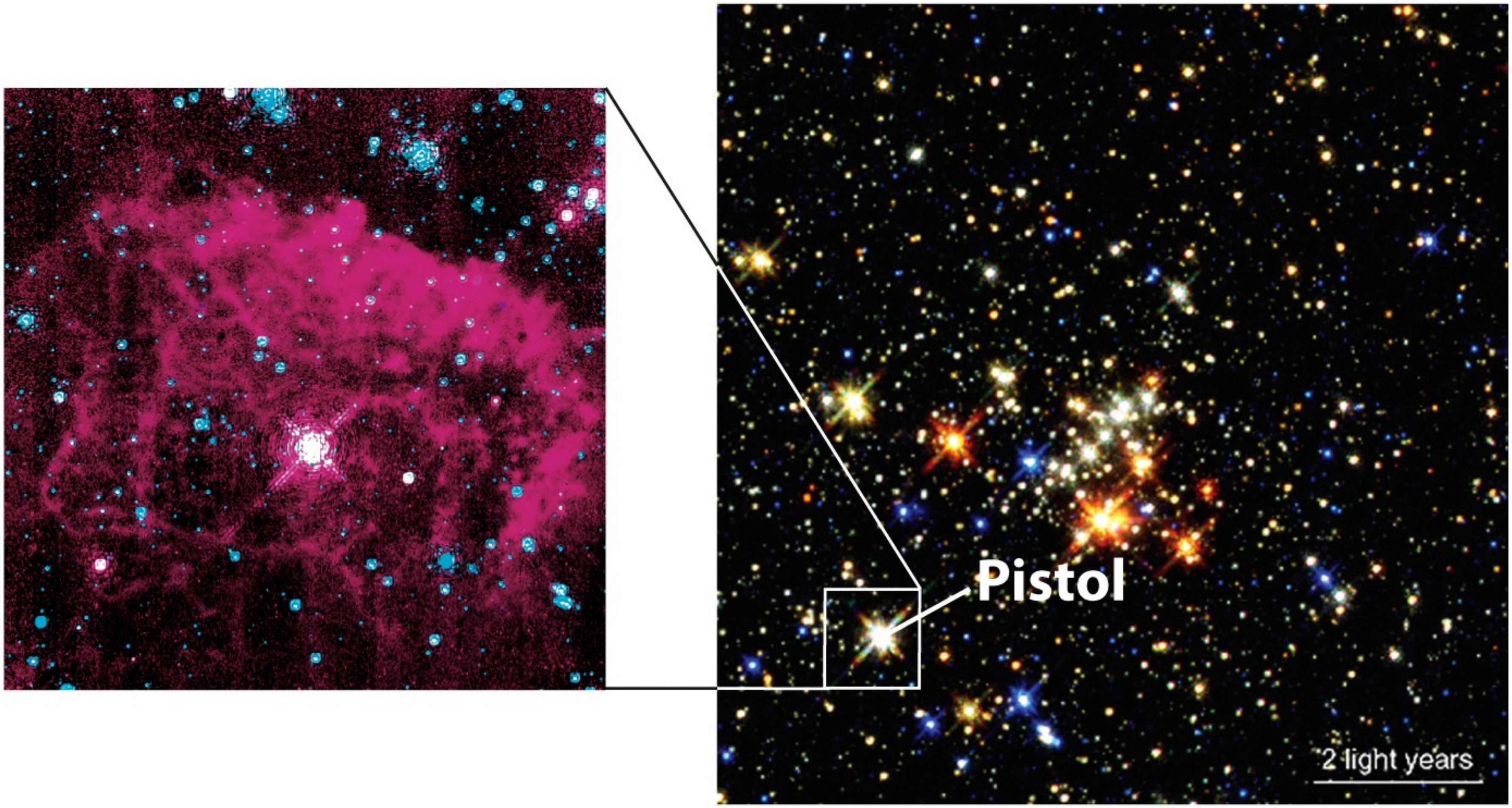
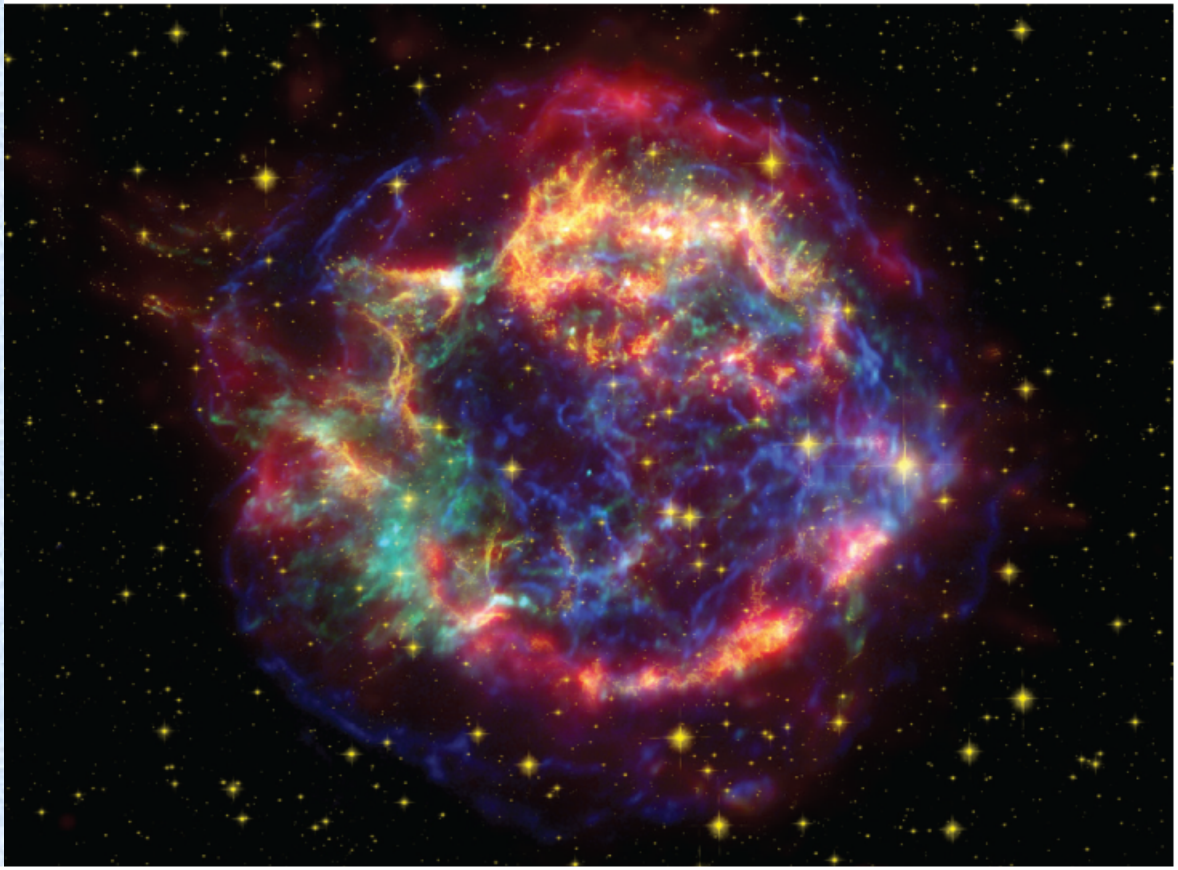


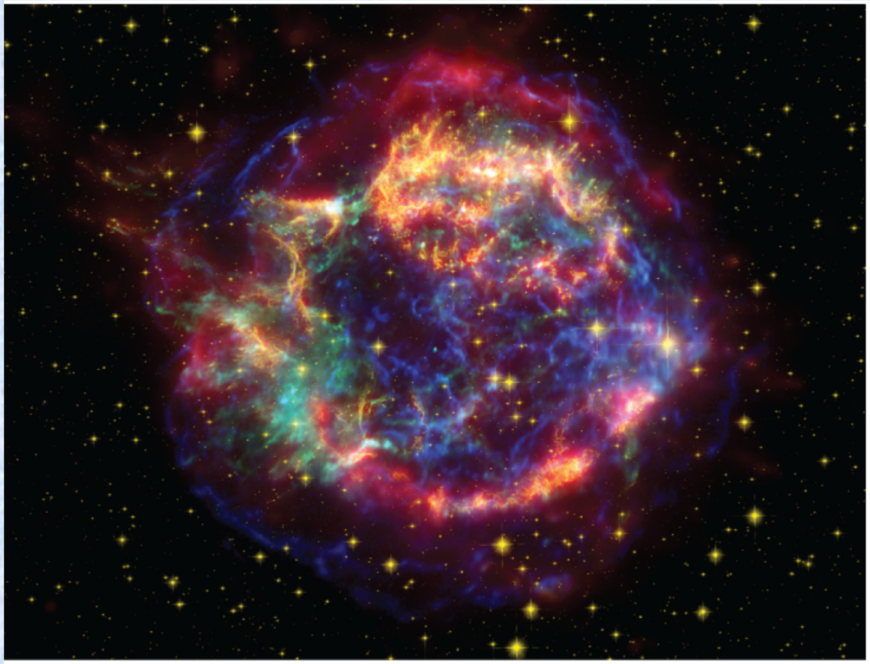
Figure 18-13
Universe, Tenth Edition
2 MASS/UMass/IPAC-Caltech/NASA/NSF; inset: D. Filger, NASA

"Feedback" from a massive star on its environment

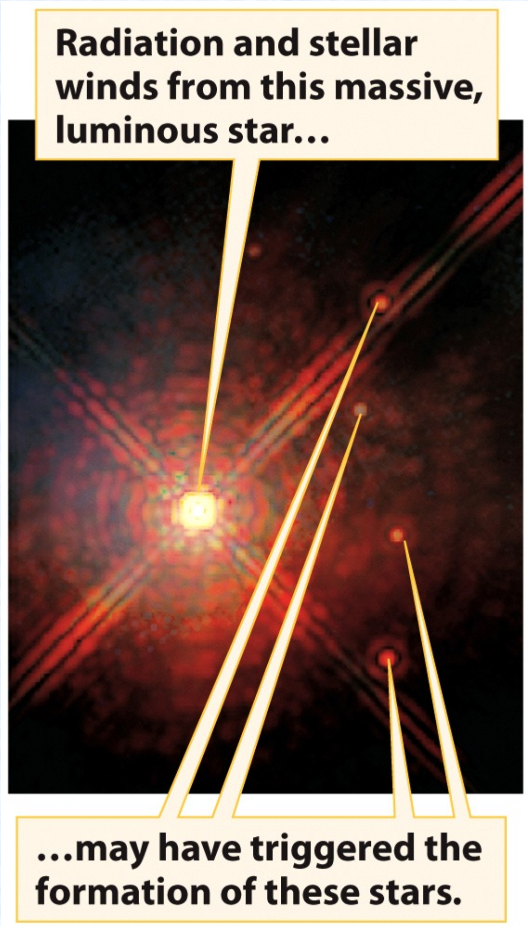


HW6 (Cassiopeia A): A massive star about 3000 pc from Earth exploded 300 yr ago. The shock wave has expanded about 3 pc. You are asked to find the expansion speed.

“Feedback” from a massive star on its environment



NASA/JPL-Caltech/Univ. of Ariz./STScI/CXC/SAO



Does this process disrupt gas clouds (negative feedback)?
Or compress them and trigger star formation (positive feedback)?

Triggered Star Formation in a Molecular Cloud

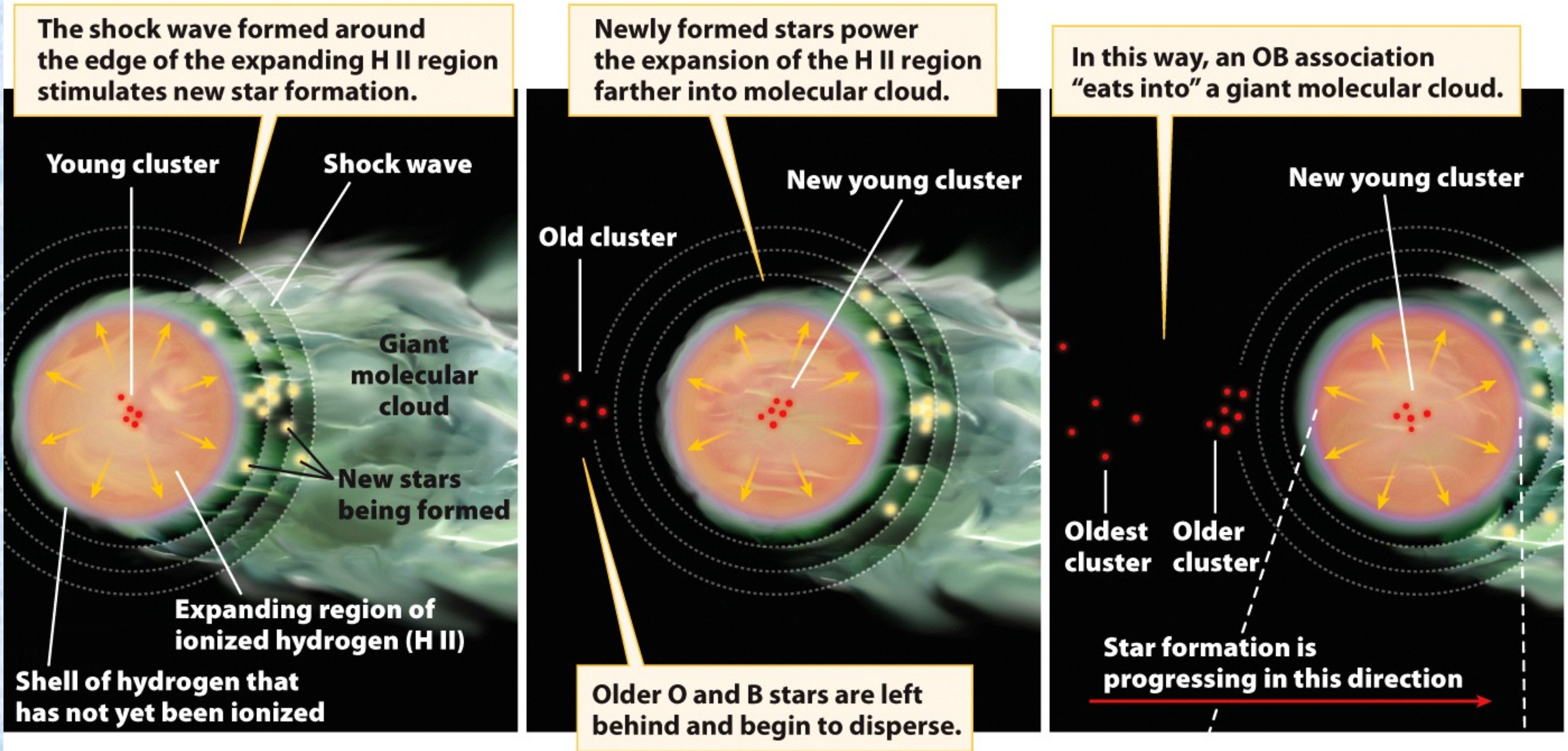


Figure 18-25 part 1
Universe, Tenth Edition

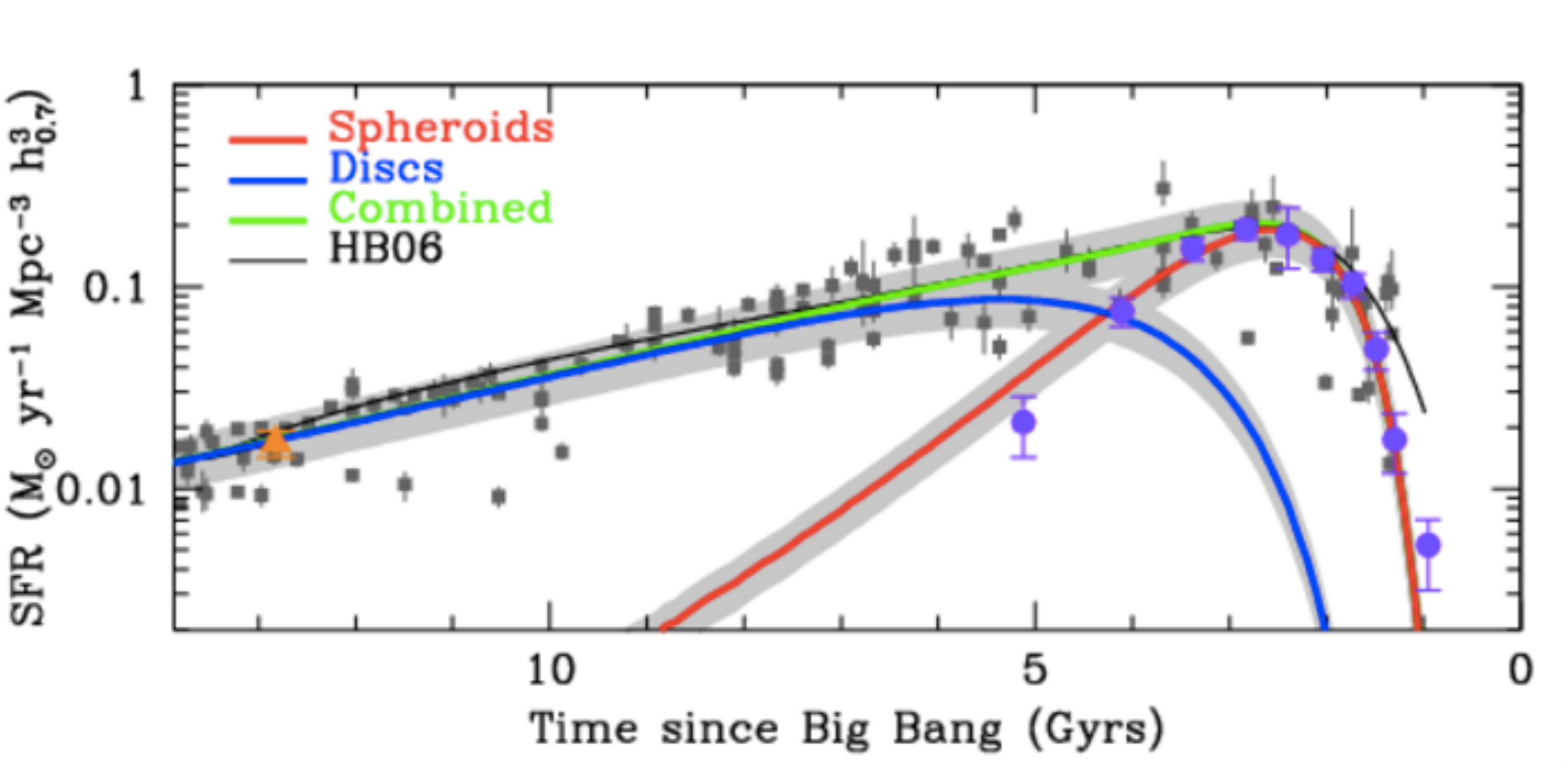
When did most of the stars in the Universe form?

Cosmic Star Formation History

TODAY

Sun formed

Peak activity
11-12 Gyr ago



How Do Stars Form from Interstellar Gas?

The interstellar medium contains dense clouds.

The densest regions of interstellar clouds form protostars.

And the protostars evolve towards the main sequence.

Question (iclickers!)

- The major source of energy in the pre-main sequence life of the Sun was
  - A) gravitational
  - B) nuclear fusion
  - C) chemical burning of carbon atoms
  - D) nuclear fission

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Stars Form within Dense Dark Nebulae (or Bok globules)

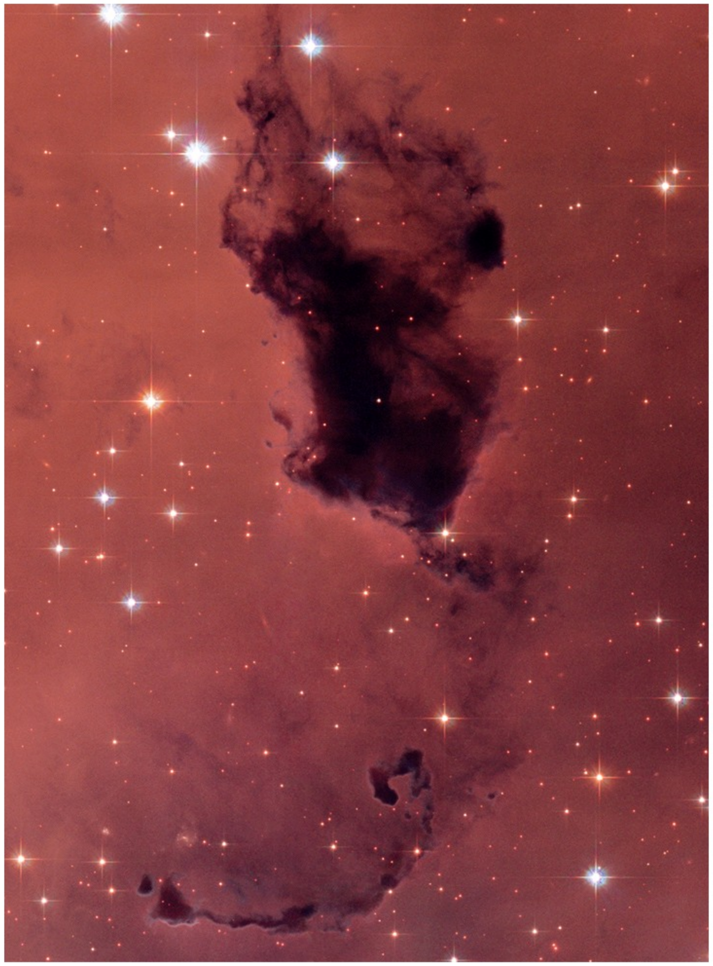
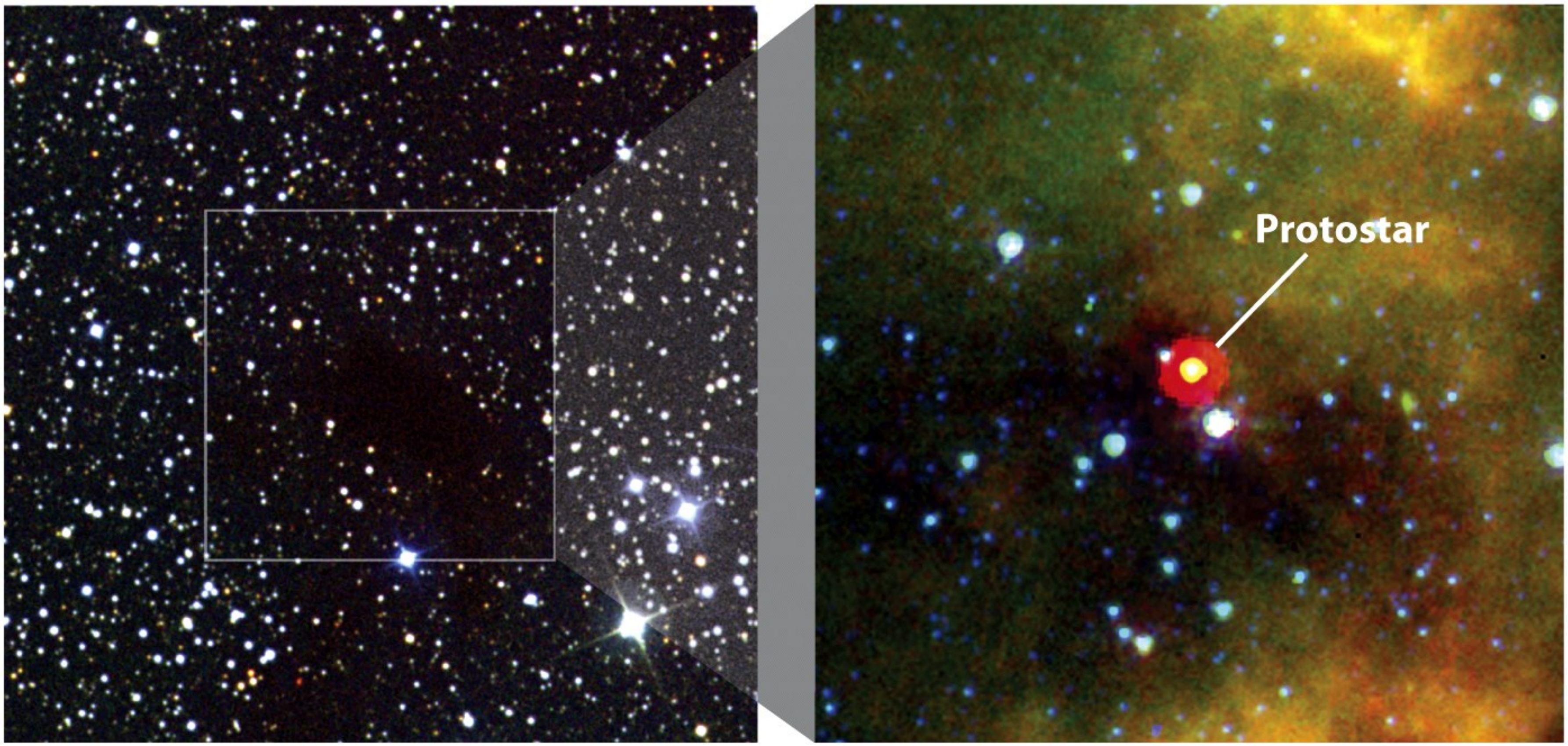


Figure 18-9
Universe, Tenth Edition
NASA, ESA, and The Hubble Heritage Team [STScI/AURA]

- About 1-3 pc across
- ~1000 M_0
- Illuminated by nearby stars (of higher mass)



(a) A dark nebula

(b) A hidden protostar within the dark nebula

Figure 18-11
Universe, Eighth Edition

Figure 18-17
Universe, Eighth Edition

Formation of a Protostar. I.

- Collapsing gas cloud releases energy to make protostar shine.
- Disks enable collapse by transporting angular momentum.

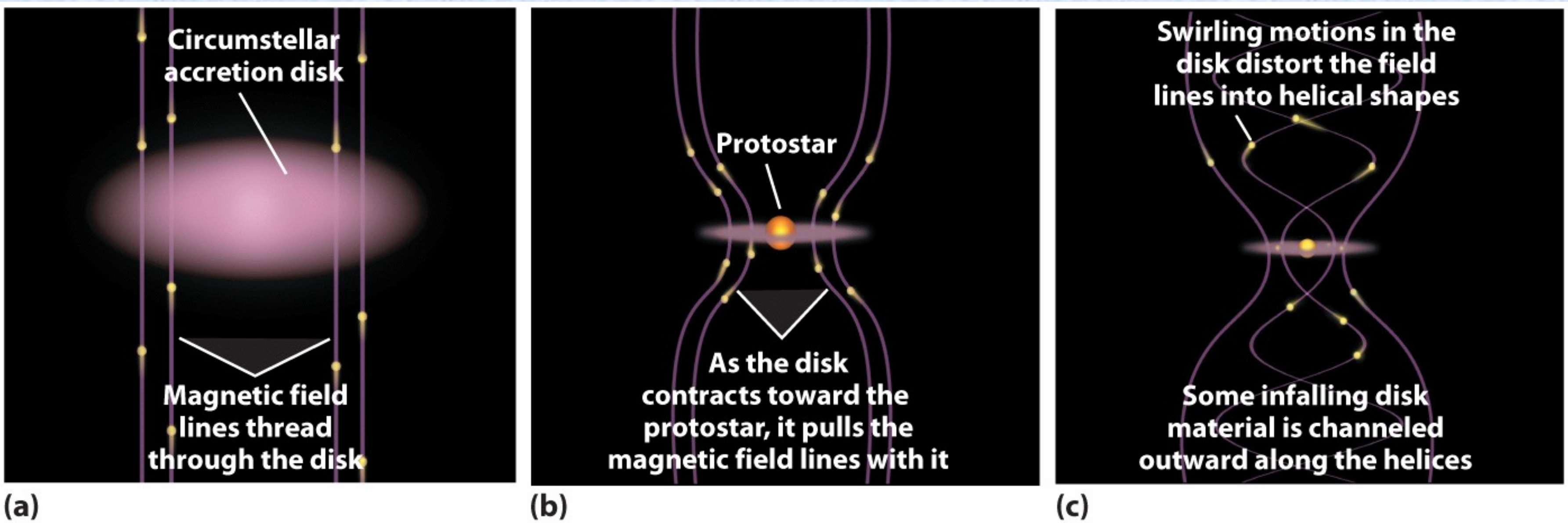


Figure 18-16
Universe, Tenth Edition

Formation of a Protostar. II.

- Collapse stops when fusion begins and establishes equilibrium.
- The minimum mass to ignite fusion is 0.08 solar masses.
- Jets feedback on the environment, stopping additional accretion.

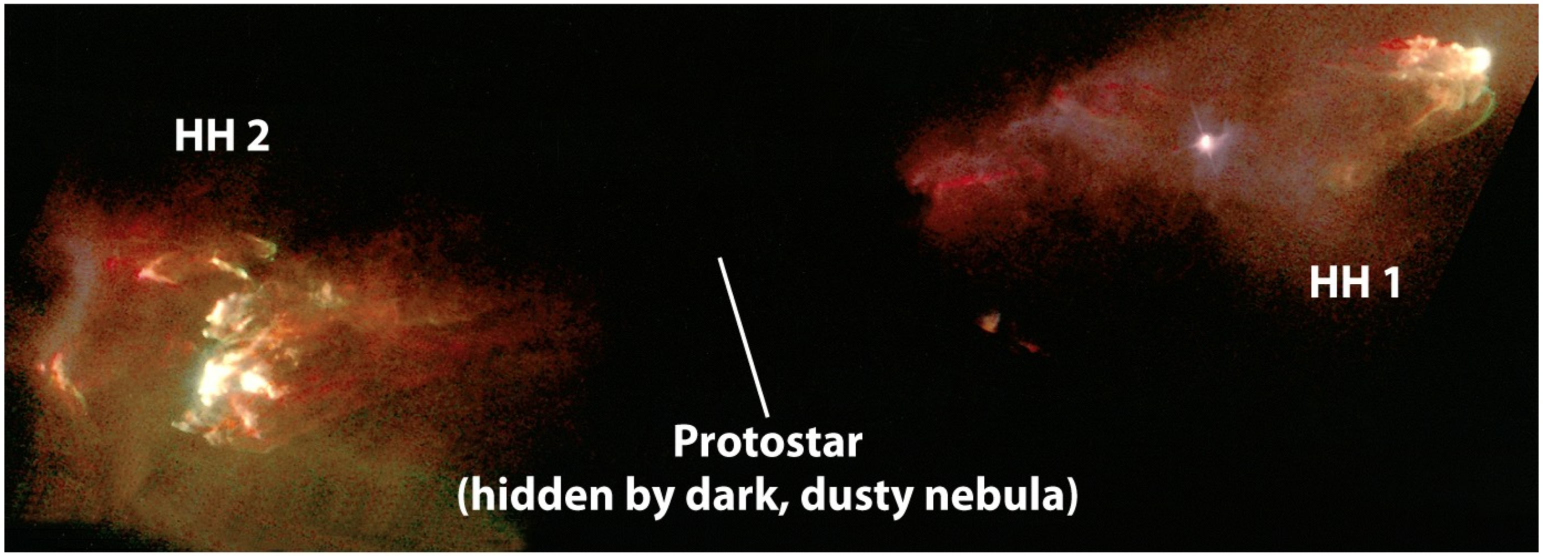


Figure 18-14
Universe, Tenth Edition
J. Hester [Arizona State University], the WFPC-2 Investigation Team, and NASA

Mass Loss and Accretion: T Tauri Stars ($M < 3\ M_0$)

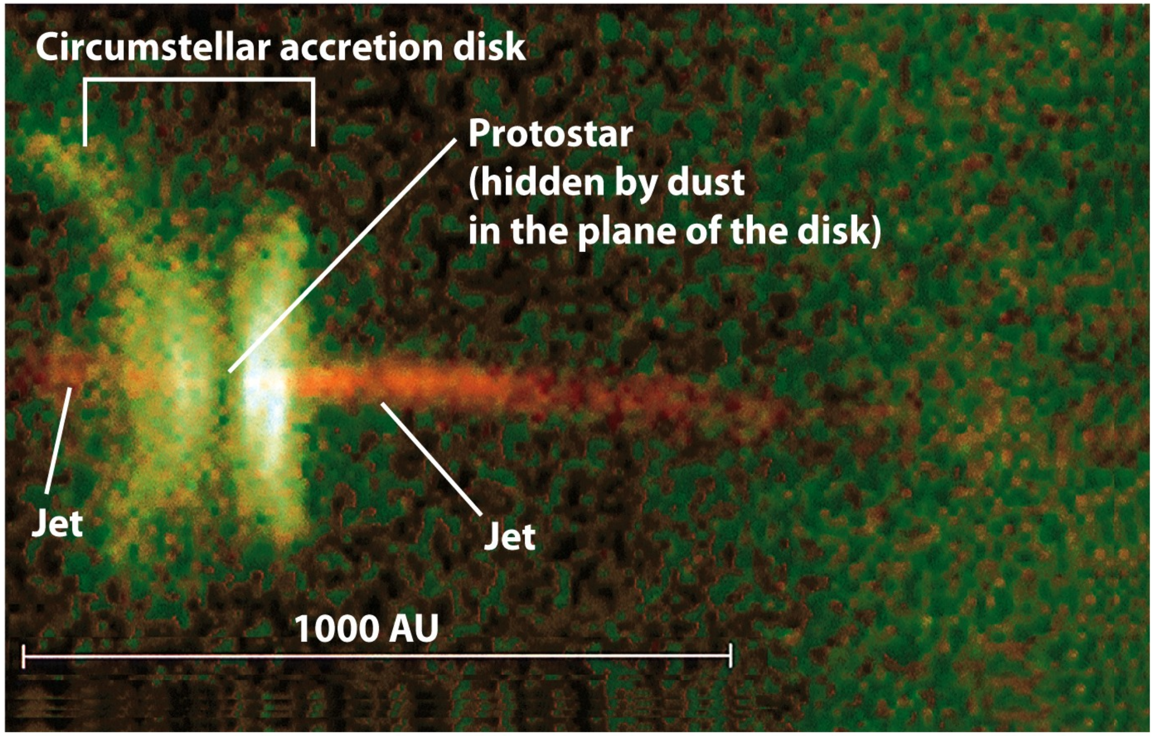
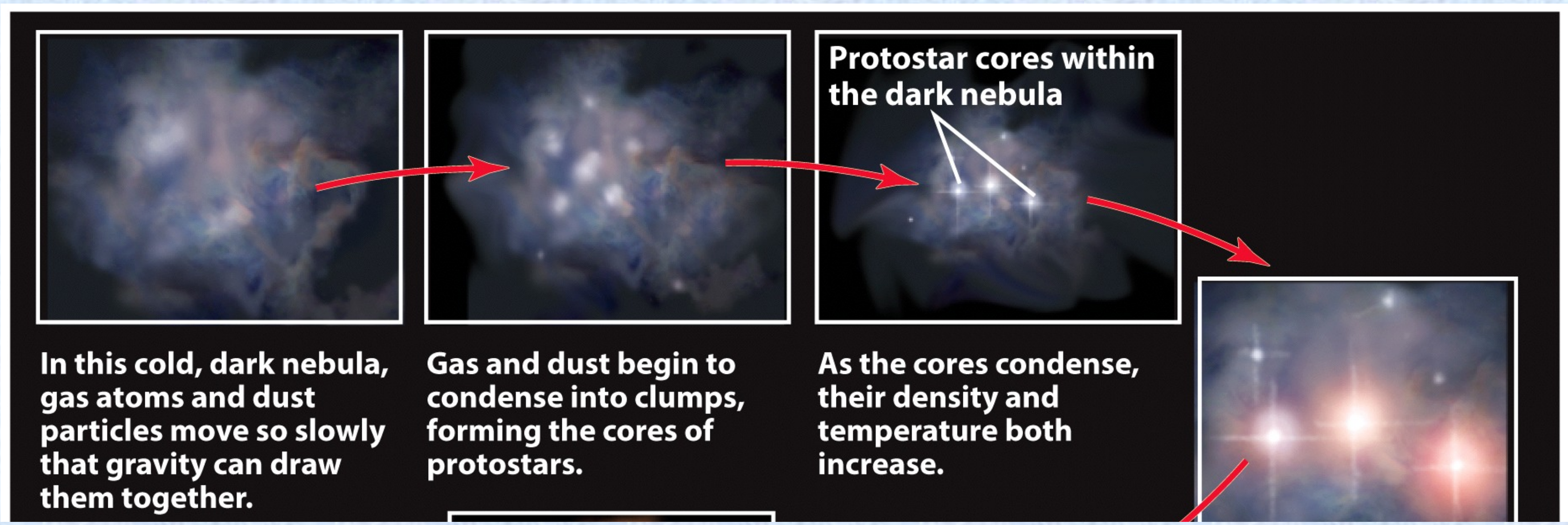


Figure 18-15
Universe, Tenth Edition
C. Burrows, the WFPC-2 Investigation Definition Team, and NASA

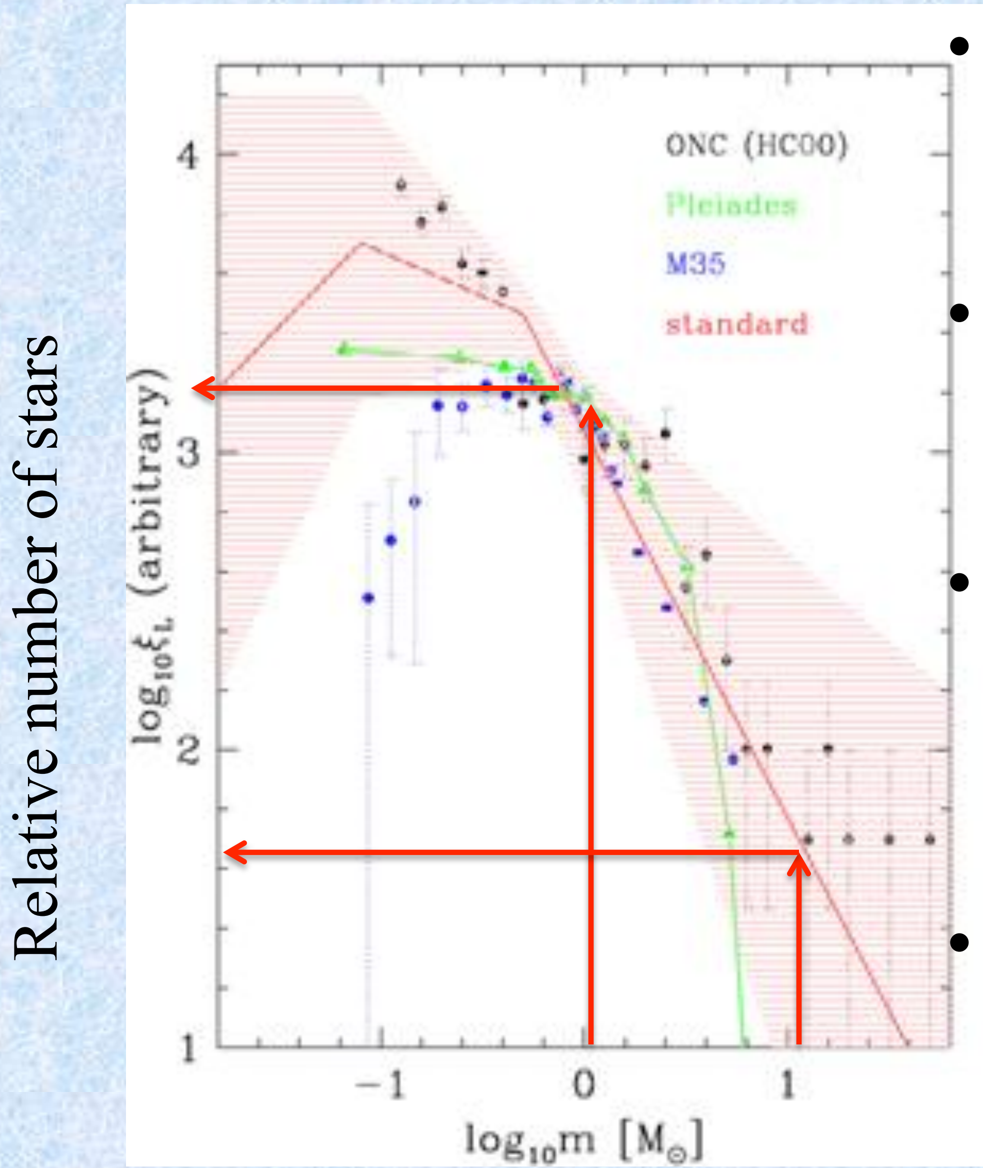
HW6 (HH 30, 130 pc from Earth, jet velocity is 200 km/s):
What is the orbital period at the edge of the disk?
How long did it take the jet to traverse the region shown?

The Clumps in Molecular Clouds Have a Range of Masses



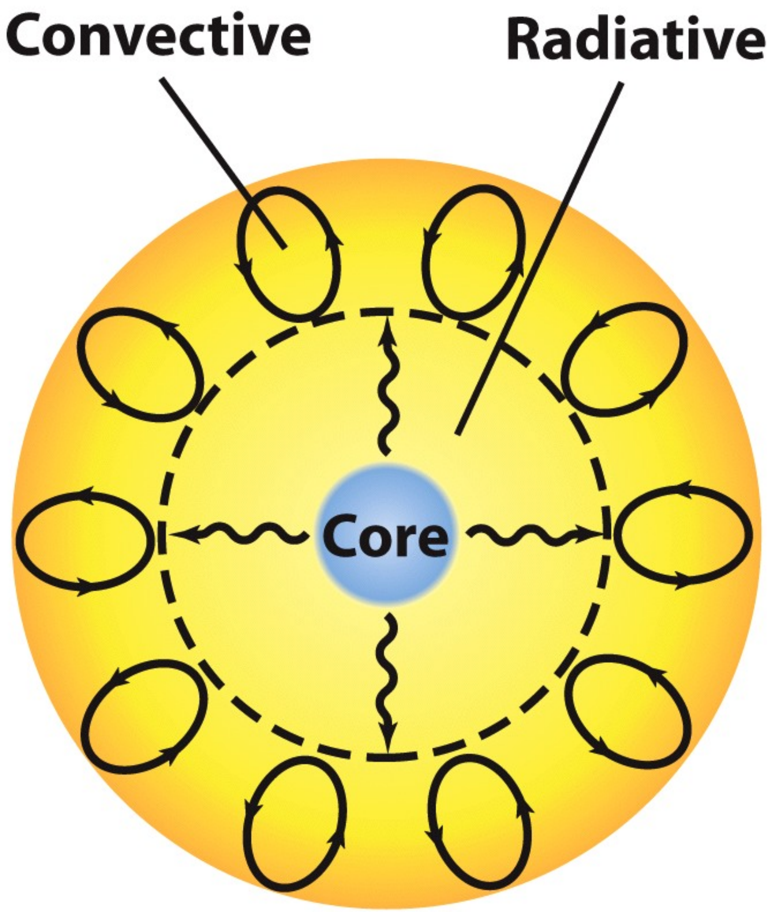
Evolution depends on mass…

Star Formation Produces a Range of Stellar Masses



- The minimum stellar mass is about 0.08 M_0. Why?
- The maximum stellar mass is roughly 100 M_0. Why?
- All star clusters show roughly the same distribution of stellar masses.
- Low mass stars are much more common than high mass stars.

Stellar Structure. I. The Sun



Mass between about 4 M⊙ and 0.4 M⊙: Energy flows by radiation in the inner regions and by convection in the outer regions.

Figure 18-12b
Universe, Tenth Edition

Stellar Structure. II.

Low Mass Stars
(M < 0.4 M_o)

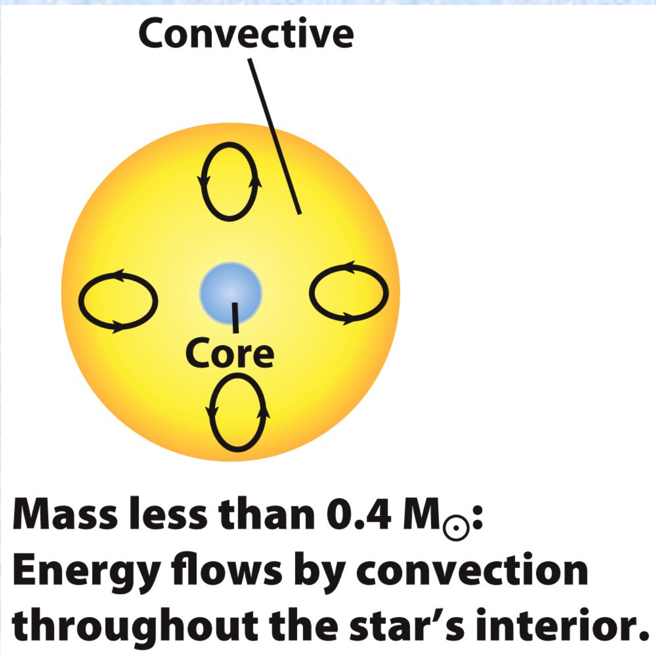


Figure 18-12c
Universe, Tenth Edition

High Mass Star
(M > 4 M_o)

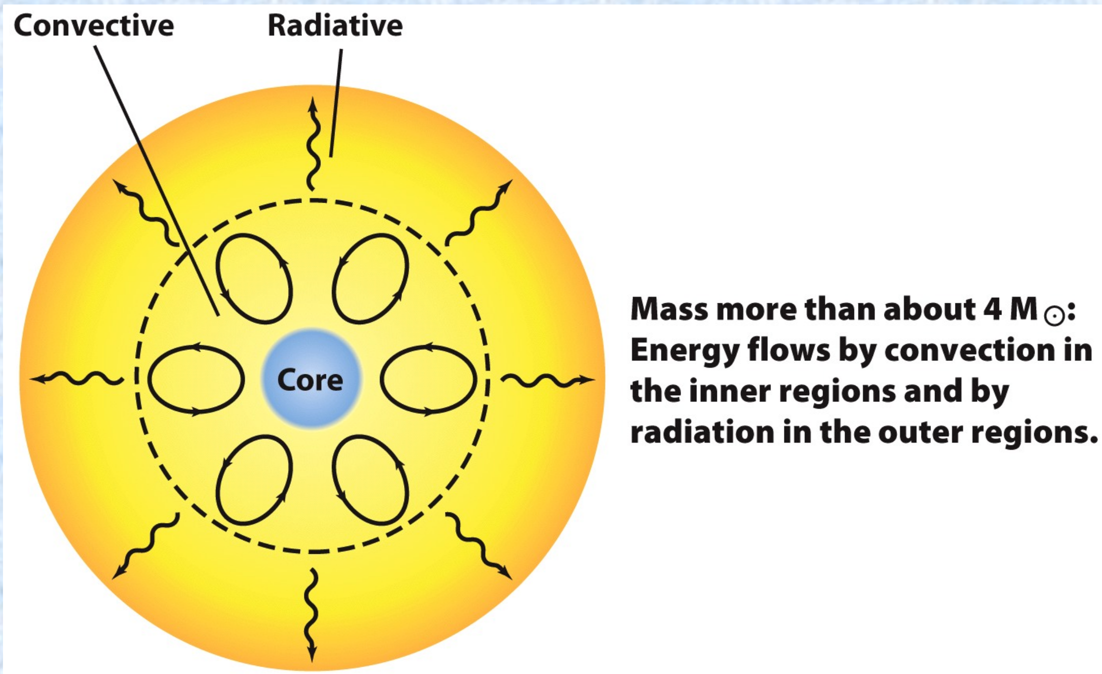


Figure 18-12a
Universe, Tenth Edition

Stars Less Massive than the Sun have Main Sequence Lifetimes Long than 10 Gyr

- Low mass stars burn H slower in their cores.
- Low mass stars have a different mass- luminosity relation ($L \sim M^x$), where $x = 2.3$ for $M < 0.43\ M_0$
- The lowest mass stars have not had time to evolve off the main sequence.
  - $0.75\ M_0$ star requires 25 Gyr to burn up its core H.
  - We don't expect to find post main-sequence stars of this mass in a Universe that is 13.7 Gyr old.

Summary

- High mass stars live fast and die young
  - Galaxies form stars in spiral arms.
  - Most of the star formation in galaxies happened 7-9 billion years ago.
- Interstellar dust makes stars appear fainter and redder than they really are.
- Stars form in clouds of cold gas, collapsing under gravitational instability
  - Protostars are heated by gravitational collapse and often form disks and jets around them
- Stellar lifetimes are a tool for understanding galaxies and the universe.
  - H-R diagrams can be used to age-date star clusters.